Clothing a model of embodiment

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Abstract: By delineating the parametric variations that affect infant performance in the standard A-not-B search task, the Thelen et al. model provides an important contribution to the field of infant development. We discuss several broad issues pertinent to interpreting the model. We note that the phenomenon modeled by Thelen et al. is not necessarily the one originally described by Piaget. We describe data on infant self-correction that are not addressed by the Thelen et al. model. Finally, we suggest that psychological constructs such as representation and knowledge structures are valuable to our understanding of the A-not-B phenomenon in particular and psychological development in general.

If Kurt Lewin were alive, he would probably be very pleased with Thelen et al.’s approach to modeling the dynamics of behavioral development. Unfortunately, his efforts to apply the principles and methods of topology to the development of a psychological field theory remained in the realm of metaphor due primarily to the unavailability of sophisticated computational power. Nonetheless, Lewin argued persuasively for studying the dynamics of the endogenous and exogenous forces that influence a child’s cognitions and social behavior in the actual and total situation of which they are a part (Lewin 1936; 1954). In some sense, the Thelen et al. model realizes Lewin’s prescient vision.

In contrast, Jean Piaget would probably not be very pleased with the Thelen et al. approach. For one thing, the phenomenon that he describes in The construction of reality in the child (1954) as the typical reaction of the fourth stage is notably different from the phenomenon that is now generally accepted as the A-not-B error. Here is Piaget’s description of the reaction:

Suppose an object is hidden at point A: the child searches for it and finds it. Next, the object is placed in B and is covered before the child’s eyes; although the child has continued to watch the object and has seen it disappear in B, he nevertheless immediately tries to find it in A (1954, p. 54)

Clearly Piaget did not posit multiple hidings at location A as a prerequisite for incorrect search at location B. In one observation of Jacquelinet at 0; 10, the object is hidden at location A twice but in observations of Lucienne and Laurent, there is usually only one hiding at location B. For example,

Obs. 42. At 0; 10 (9) Lucienne is seated on a sofa and plays with a plush duck. I put it on her lap and place a small red cushion on top of the duck (this is position A); Lucienne immediately raises the cushion and takes hold of the duck. I then place the duck next to her on the sofa in B, and cover it with another cushion, a yellow one. Lucienne has watched all my moves, but as soon as the duck is hidden, she returns to the little cushion A on her lap, raises it and searches. An expression of disappointment; she turns it over in every direction and gives up. (1954, p. 57)

This point is vitally important here because it is not obvious that the Thelen et al. model would predict a strong tendency toward perseveration after a single trial at location A. The vast literature based on the Uzgiris and Hunt (1975) formalization of the A-not-
the target article. Under the proper parameter settings, the cooperative (interactive) term in the field equations will lead to phase transitions that generate the desired dynamics. By emphasizing the dynamics arising from the interaction term (sect. 4.1.3), the task input (sect. 4.2.1), $S$—{$\text{task}$}(x, t)/$S$, and the memory input (sect. 4.2.1), $S$—{$\text{mem}$} (x, t)/$S$, become redundant.

The interaction term introduces instabilities into the system so that the choice of A versus B arises from small perturbations of the dynamical field (sect. 4.1.1), $u(x, t)$. These instabilities are analogous to those in the visual system that have been suggested as an underlying mechanism for certain visual hallucinations (Ermentrout & Cowan 1979). In the present case, the instabilities lead to cooperativity that represents movement direction probabilities in the space of motor activity.

By encapsulating the cognitive choice of the hidden toy’s location in terms of motor representations, the authors are able to tie their formalism to population codes (Georgopoulos 1996). The connection would be more complete if the memory were embedded in neural structures of the cerebral cortex. If the theory were truly “embodied,” then $S$—{$\text{mem}$} (x, t)/$S$ inputs might be contained in the interaction term and represent synaptic interactions.

2. Critical fields persevere. Analysis and simulations can be used to study pattern formation on the one-dimensional domain that represents the movement space. The following analysis shows the existence of instabilities that yield a phase transition in the configuration space of the field $u(x, t)$. Results of simulations are presented that yield the behavior near the critical point of the phase transition between disordered and fixed behavior. Because the movement space is represented as the direction of reach from the sitting child, the domain encompasses a circle. The fixed behavior would appear as oscillations in the field value around the circle. High field values over a particular value of $x$/$S$ would represent a high probability of a reach in that direction.

To find the natural wavelength generated by the interaction term our starting point is the field equation (3), $\partial_t \{u(x, t)/S\} = \partial_x \{u(x, t)/S\} + S(x, t)/S$. The interaction term is a convolution of a threshold function of the field, $\phi(u(x))/S$ with the interaction kernel. To simplify matters for the analysis, we use the exact expression in the simulation, we can expand the threshold function so that, $\phi(u(x)) = u(x) + 6c$ where $\phi$ is a solution to the field equations. Instabilities decay if the growth factor $S$ is negative for all wave numbers $k$ for oscillations exist.

The result is that oscillations appear on the order of the system size. That is, a single reach direction will appear as a region of high field activity, and the reach will be frozen in that direction. Thus the frozen phase spontaneously generates the task input, $S$—{$\text{task}$} (x, t)/$S$. However, with sufficient noise in the system, the instability is overwhelmed and there would be no preferred direction so that no reaching is manifest. If the noise, or the interaction kernel, is properly tuned so that the system is near the transition, then spontaneous reaching occurs in random directions. A simulation confirms these analytic results, as shown in Figure 1. In this simulation, the field $u(x)/S$ is discretized into a set of interacting units, and the noise is set so that the field solution is near the critical point. Two perturbations are introduced: a cue to target A, $S$—{$\text{task}$}(x)/$S$, and a memory of target B that is encoded as a slight increase in the interaction kernel in the vicinity of target B. In this simulation, the memory does not fade.

Spontaneous switching between the two targets is seen in part A of the figure. The simulation also shows another feature of field behavior near the critical point: high susceptibility. The region of high field activity is the result of very small perturbations, so small that no result would be seen in higher noise conditions. Part B of the figure shows the result of an average over many trials for three different intensities of the cue. It is interesting that there can be stronger memory behavior with a small cue (dashed trace) than with no cue at all (dotted trace).

Figure 1 (Roberts). Simulation of field dynamics near the critical point. The cue input is located at target A ($-60^\circ/0$) and the interaction is slightly increased at target B ($70^\circ/0$) to represent memory effects. (A) Dynamical field amplitude of $u(x,t)$. Grey scale represents amplitude from lowest (white) to highest (black). Random switching takes place between target A ($\theta \in [1,13]$) and target B ($\theta \in [70,100]$). (B) Average of the dynamical field amplitude over $\theta$-$\theta$ [1,4000] for simulations with no cue input (dotted trace), moderate cue input (dashed trace), and large cue input (solid trace).

3. Critical connections to the brain? The conclusion we may draw from this exercise is that undecided movements crystallize into a decision as the system balances on the edge of a critical point. In the target article, the weak link to embodiment is in the physiological connection to motor population coding (Georgopoulos 1996). The memory term could be embedded in the interaction term with synaptic interaction yielding the form of the interaction kernel and perhaps synaptic plasticity regulating the strengths of the synapses. This is not unrealistic, given the known cortical interactions of local excitation and lateral inhibition. However, embodiment of the theory would require a kind of “kinetopy” that has not been found in the motor cortex. In their attempt at embodying cognition, the authors must be careful not to “disembody” motor control.